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Near field wireless power transfer using curved relay resonators for extended transfer distance

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Abstract. This paper investigates the performance of a near field wireless power transfer system that uses curved relay resonator to extend transfer distance. Near field wireless power transfer operates based on the near-field electromagnetic coupling of coils. Such a system can transfer energy over a relatively short distance which is of the same order of dimensions of the coupled coils. The energy transfer distance can be increased using flat relay resonators. Recent developments in printing electronics and e-textiles have seen increasing demand of embedding electronics into fabrics. Near field wireless power transfer is one of the most promising methods to power electronics on fabrics. The concept can be applied to body-worn textiles by, for example, integrating a transmitter coil into upholstery, and a flexible receiver coil into garments. Flexible textile coils take on the shape of the supporting materials such as garments, and therefore curved resonator and receiver coils are investigated in this work. Experimental results showed that using curved relay resonator can effectively extend the wireless power transfer distance. However, as the curvature of the coil increases, the performance of the wireless power transfer, especially the maximum received power, deteriorates.

1. Introduction

Recent developments in printing electronics and e-textiles have seen increasing demand for embedding electronics into fabrics for wearable applications. One of the difficulties with such applications is how to provide a sufficient and reliable power source. Traditional batteries are not an ideal solution for this application because its bulky size makes it difficult to be integrated into fabrics. Furthermore, they have limited capacity and, therefore, require constant maintenance such as replacement or recharging. Research on flexible energy storage devices, such as batteries and supercapacitors, has been reported [1][2] but their capacity and performance to date are relatively poor compared to traditional batteries.

Energy harvesting concerns conversion of ambient energy into electrical energy and can potentially be used to power electronics in wearable applications. Ambient energy sources in this application include human movement, temperature difference and ambient light. However, these energy

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harvesting techniques rely significantly on the ambient environment which is unpredictable in wearable applications. Therefore, the amount of energy generated is unpredictable which makes it not a reliable power source for this particular application.

By contrast, active power transfer techniques, such as wireless power transfer [3], are more reliable and suitable for powering wearable devices. Near field wireless power transfer is one of the most promising methods. It operates based on the near-field electromagnetic coupling of coils. This concept can be applied to body-worn textiles by, for example, integrating a transmitter coil into upholstery, and a flexible receiver coil into garments. Flexible textile coils take on the shape of the supporting materials such as garments and, therefore, tend to bend during operation.

The performance of the near field wireless power transfer system is a strong function of the alignment [4] and separation of the inductively coupled coils. Near field wireless power transfer systems can transfer energy over a relatively short distance which is of the same order of dimensions of the coupled coils. Previous work [5] has shown that the energy transfer distance can be increased using flat relay resonators. In this paper, performance of a near field wireless power transfer system that uses a curved relay resonator to extend transfer distance is investigated.

2. Experimental

2.1. Experimental setup

Figure 1 shows the experimental setup. The transmitter coil is driven by a fixed frequency driver. The transmission frequency is set as 250 kHz before other coils are coupled. A relay resonator consisting of a relay coil and a matching capacitor, C1, is placed between the transmitter and receiver coils. The receiver coil is connected in parallel with the tuning capacitor C2. The AC input is rectified using a bridge rectifier. The rectified DC voltage across a variable load resistor R_L , V_L , is measured and received DC power can then be calculated by V_L^2/R_L . V_L was measured across various R_L , thus, the maximum received DC power across the optimal load resistor can be determined.

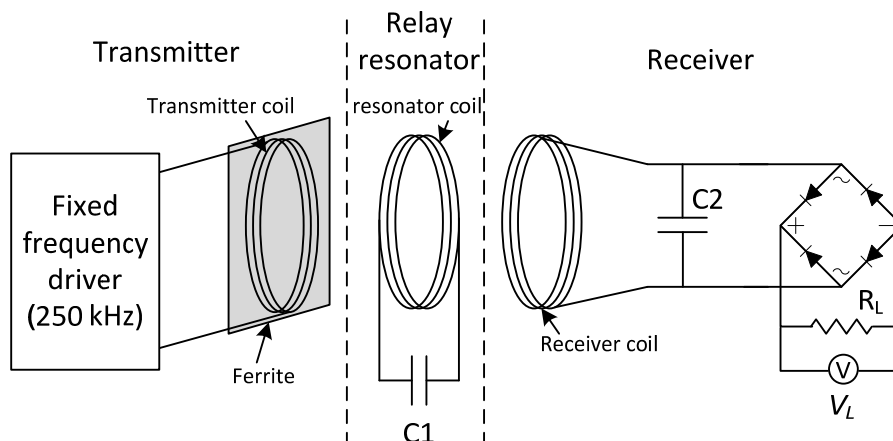


Figure 1. Experimental setup concept.

All coils used in the test are a typical coil used in commercial Qi compatible receivers. Details of the coil can be found in [6]. The inductance of the coil was measured as 7.98 μH without the ferrite back and 10.88 μH with the ferrite back, respectively. The coil is 300-micron thick and therefore is relatively flexible without the ferrite back. It can be bent to make a curved coil. The inductance of the coil reduces as the coil bending curvature increases. When the bending curvature is 0.057 m^{-1} , which is the maximum of all coils used in the test, the coil inductance was measured as 7.017 μH without the ferrite back. Figure 2 shows the practical implementation of the testing circuit.

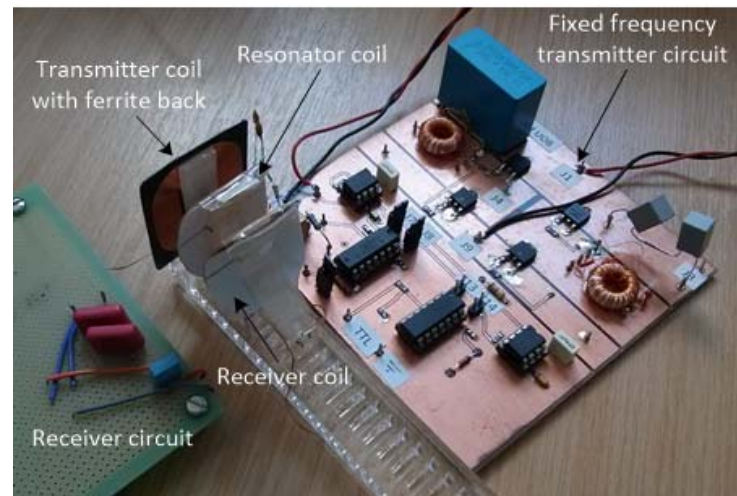


Figure 2. Practical implementation of the testing circuit.

2.2. Coil arrangement

Figure 3 shows the two coil arrangements that were studied. In both arrangements, the transmitter coils are flat and have ferrite backs. The centres of the transmitter and receiver coils are separated by a distance of d . The relay resonator coil is placed in the middle of the transmitter and receiver coils, i.e. the centre of the resonator coil is $d/2$ apart from both the centres of the transmitter and receiver coils. The resonator and receiver coils in arrangement 1 have lower curvatures than those in arrangement 2.

| | Arrangement 1 | | | Arrangement 2 | | |
|----------------------------------|---------------|--------|-------|---------------|--------|-------|
| | TX | RES | RX | TX | RES | RX |
| | | | | | | |
| $\kappa \text{ (m}^{-1}\text{)}$ | 0 | 0.0065 | 0.013 | 0 | 0.0465 | 0.057 |

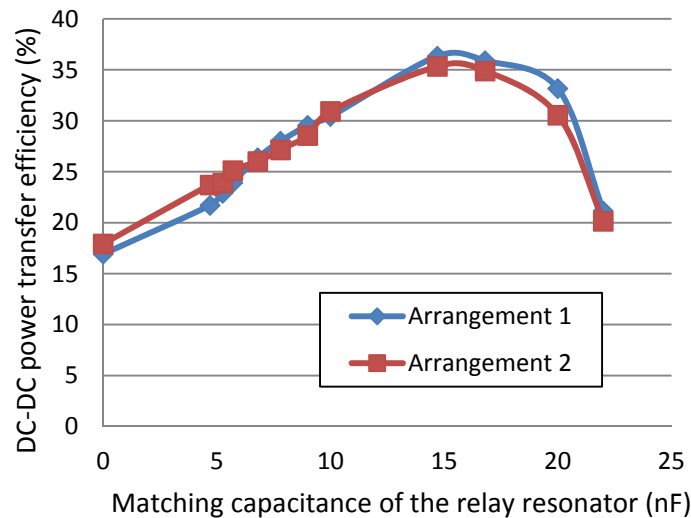
Figure 3. Side view of the two coil arrangements that were tested (TX: transmitter, RES: relay resonator, RX: receiver). Coil bending curvature, κ , is shown beneath the respective coil. Coils in arrangement 1 have lower curvature than those in arrangement 2.

3. Results

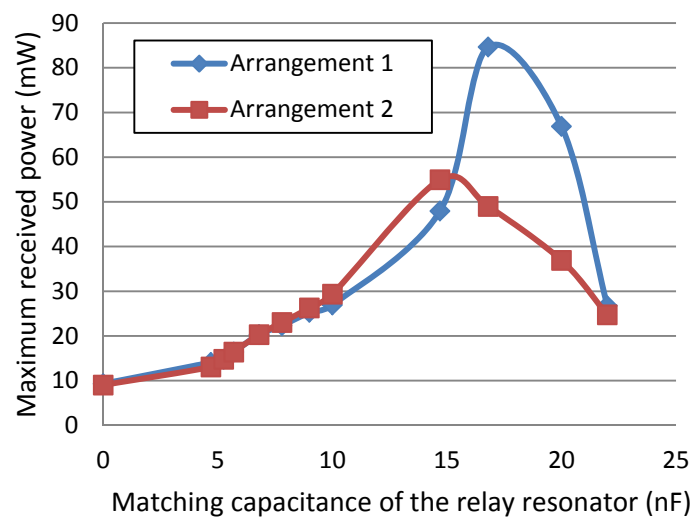
3.1. Matching capacitor of the relay resonator

In the test, a variable matching capacitor was first connected to the relay resonator coil to find the optimum value. Figure 4 shows comparisons of DC-DC power transfer efficiency and maximum received power with variations of matching capacitances of the relay resonator in the two coil arrangements. It was found that the DC-DC efficiency reached maximum with a 14.7 nF matching

capacitor in both coil arrangements. In terms of maximum received power, arrangement 1 requires a 16.8 nF matching capacitor while arrangement 2 requires 14.7 nF. Therefore, 16.8 nF and 14.7 nF capacitors were connected to resonator coils in arrangements 1 and 2 respectively.



(a) DC-DC power transfer efficiency



(b) Maximum received power

Figure 4. Comparisons of DC-DC power transfer efficiency and maximum received power with variations of matching capacitance of the relay resonator in the two arrangements.

3.2. Comparisons of experimental results

In the test, three scenarios were considered for each coil arrangement. In the first two scenarios, no relay resonators are used and the TX and RX coils are separated by 10 mm and 20 mm, respectively. In the third scenario, the TX and RX coils are separated by 20 mm and a relay resonator is used as shown in Figure 3. Table 1 compares performance of wireless power transfer in terms of DC-DC power transfer efficiency and maximum received DC power for the three scenarios in each of the two arrangements. An optimum matching capacitor was connected to the receiver coil in all scenarios. The optimum matching capacitor in each scenario was determined using the same method described in Section 3.1.

It was found that using a curved relay resonator can effectively increase both DC-DC power transfer efficiency and the maximum received power over a longer transfer distance. For arrangement 1, the DC-DC power transfer efficiency and the maximum received power are increased by 114.7% and 809.7% by using a relay resonator, respectively. For arrangement 2, these two values are increased by 132.2% and 590.7% respectively by using a relay resonator. The increase in the DC-DC power transfer efficiency is similar in both arrangements while maximum received power is reduced as coil curvature increases.

Table 1. Comparisons of performance of the wireless power transfer system with and without the relay resonator.

| | Arrangement 1 | | | Arrangement 2 | | |
|--|---------------|------|------|---------------|------|------|
| Using relay resonator? | No | No | Yes | No | No | Yes |
| Distance between TX and RX coils, d , (mm) | 10 | 20 | 20 | 10 | 20 | 20 |
| DC-DC power transfer efficiency (%) | 46.4 | 16.9 | 36.3 | 41.8 | 15.2 | 35.3 |
| Maximum received power (mW) | 66.8 | 9.3 | 84.6 | 42.4 | 7.89 | 54.5 |

4. Conclusion

This paper investigates the feasibility of using curved relay resonators to extend the wireless power transfer distance. A basic test platform was built and two coil arrangements with different coil bending curvatures were tested. Experimental results showed that, like using relay resonators with flat coils, curved coil relay resonator can also effectively extend the wireless power transfer distance. However, the performance becomes worse as the coil bending curvature increases.

This technique can potentially be applied to wearable applications, especially those using flexible textile based coils which is likely to bend during operation. Future work include using more curved relay coils to further extend the transfer distance as well as implementing the technique using textile based coils that was demonstrated previously in [4].

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